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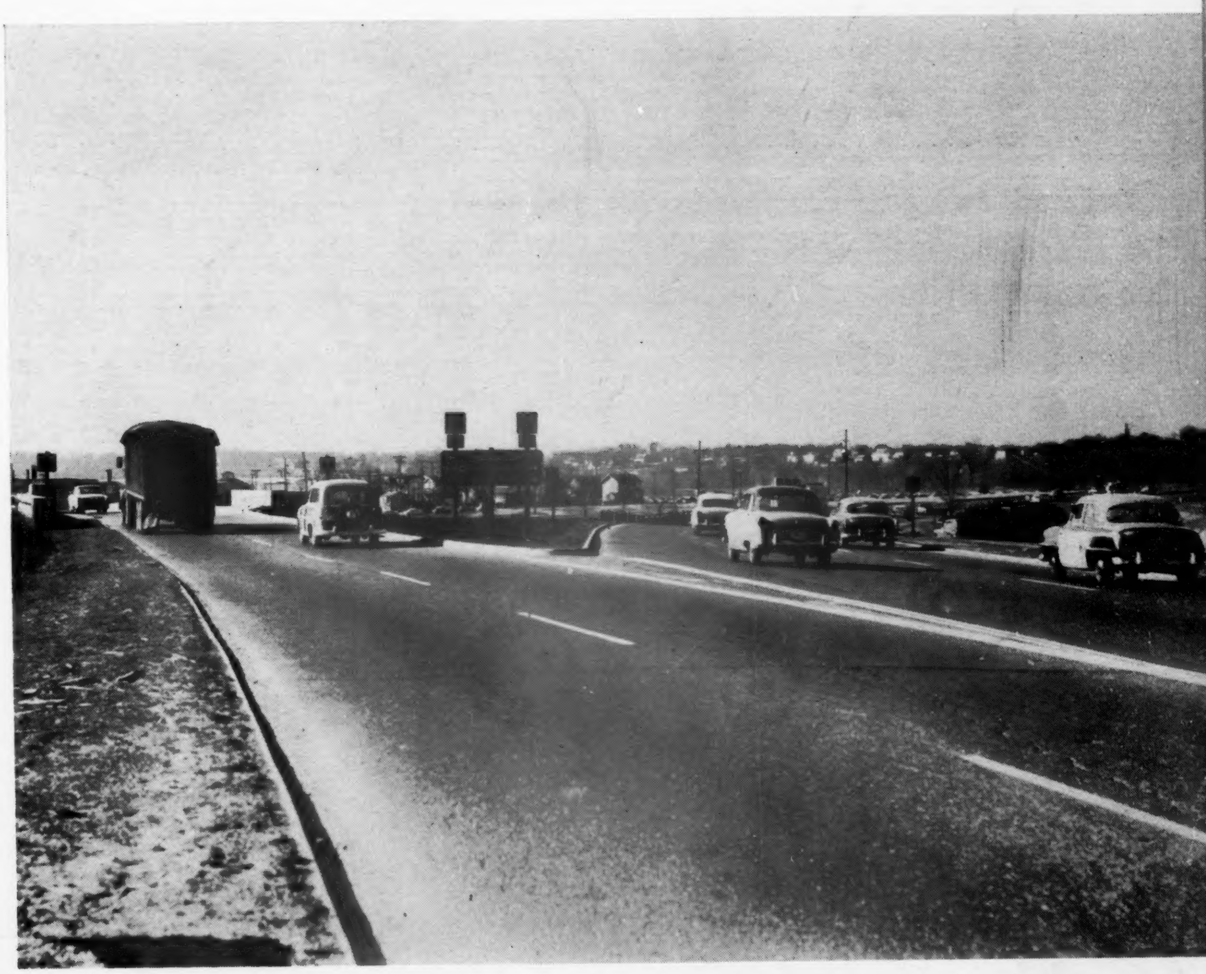
Public Roads

A JOURNAL OF HIGHWAY RESEARCH



PUBLISHED BIMONTHLY BY THE BUREAU OF PUBLIC ROADS, U. S. DEPARTMENT OF COMMERCE, WASHINGTON

In this issue: A study of nighttime legibility of highway signs with white reflectorized letters on a dark background (jct. of U. S. 1 and Virginia Route 350, Arlington County).

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C. M. Billingsley, *Editor*

BUREAU OF PUBLIC ROADS

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IN THIS ISSUE

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The printing of this publication has been approved by the Director of the Bureau of the Budget, Mar. 17, 1955.

The Effect of Letter Width and Spacing on Night Legibility of Highway Signs

BY THE HIGHWAY TRANSPORT RESEARCH BRANCH
BUREAU OF PUBLIC ROADS

Reported [1] by DAVID SOLOMON
Highway Transport Research Engineer

This study was undertaken to determine the effect that spacing between letters of words, used in highway signs, had on their nighttime legibility. More than 2,500 observations were made by 36 observers while driving an automobile at 30 miles per hour. White reflectorized letters, 10 inches high, were displayed on a black nonreflectorized background. Three different alphabets were used. Two of these, the standard Series C with narrow letters and the wider Series E, were cut from reflective sheeting. The third alphabet, identified as Series ED and similar in width to the Series E, was designed by a manufacturer using 1¼-inch-diameter plastic reflectors to form the letters. The spacings between letters were increased as the lengths of the six test words were extended from normal to 20, 40, and 60 percent above normal.

As interletter spacing was increased, the legibility distances also increased for all three alphabets until word lengths were 40 percent above normal. The resulting gain in legibility at this point was 15 percent for Series C, 16 percent for Series E, and 7 percent for Series ED. Beyond the 40-percent increase in word length, legibility leveled off or declined.

When word lengths were normal or no more than 10 percent above normal, test signs with the Series ED alphabet were found to have greater legibility. At wider spacings, the Series E alphabet was superior.

As might be expected, the 10-inch Series E alphabet was legible at a greater distance (118 to 142 feet) than the narrower 10-inch Series C alphabet at corresponding letter spacings. On a percentage basis, the differences in legibility favoring the Series E alphabet ranged from 23 percent to 27 percent. A word with letters of the Series C alphabet is shorter in length than one with letters of the Series E for a given spacing, and a comparison of legibility distance per inch of word length showed that the Series C alphabet was somewhat superior to the Series E. Also studied was the probable effect of increasing the letter height of the narrower alphabet until the legend area equaled that of the wider alphabet. At the point of equivalent legend area and spacing, the two alphabets proved to be equally legible.

The study findings point to the importance of sign proportions and provide an improved means for efficient determination of legend design. Where vertical dimensions restrict sign letter heights to something less than desirable, increased spacing between letters can help to compensate for the loss of legibility distance that would otherwise occur.

IN recent years, increasing use has been made of white reflectorized letters on a dark background for large highway destination signs. Although there are some conflicting reports, the weight of the evidence indicates that, for night legibility of large letters, this combination is superior to dark letters on a white reflectorized background. Consequently, a design using white reflectorized letters on a dark background was selected for signs recently installed on the Pentagon road network just outside of Washington, D. C. Standard alphabet designs for highway signs developed by the Bureau of Public Roads were employed.

The letter spacings used for the design of the Pentagon network signs were originally devised from limited tests and previous researches dealing with letter spacing and legibility, all with black letters on a white background. The spacing values were selected so that the white areas between successive letters in a given word would appear equal.

It was surmised that if the letter spacings were not changed the color and reflectorization reversal on the new signs might have a significant effect on night legibility. Furthermore, a recent laboratory study [2] had shown that white reflectorized letters on a black background may improve in legibility if the letter spacing is somewhat wider than that used with black on white. No definitive research looking toward the establishment of optimum spacings between letters had been conducted under actual roadway driving conditions.

The present study, therefore, was initiated to investigate the effect on nighttime legibility of increasing the spacing between white reflectorized letters on a black background.

Study Conditions

The study site was a bituminous-surfaced parking lot, 1,500 feet in length, substantially level and unused at night. The area was without illumination except for a few fixed street lights in the distant background. Thus the conditions were similar to those found on unlighted urban freeways or rural highways near cities.

Studies were conducted during March and April of 1955. Observations began after dark and continued until 11 p. m. or midnight. Generally, the weather was fair and no moon was present, although some data for 4 of the 36 observers were recorded during a light rain, and the observations of 2 others were recorded in the presence of a quarter moon. The light rain and moonlight had no apparent effect on the results obtained.

Observers were 36 male employees of the Bureau of Public Roads and of the District of Columbia Department of Vehicles and Traffic. They ranged in age from the middle twenties to the late sixties, and 20 wore eyeglasses. The participants were chosen largely because of their willingness to work in the evening hours, rather than for any particular physical ability or characteristic.

All but 2 of the 36 observers drove one of three 1951 model Pontiacs. A fourth Pontiac, 4 years older, was used by the remaining observers. The test vehicles were equipped with the improved "50–40" sealed-beam headlamps to simulate the best possible visual conditions. The headlamps were checked periodically for proper aim. The new "50–40" headlamps are now legal in all States and all vehicles in production are being equipped with them.

A test panel, 6 feet long by 4 feet high, was mounted at one end of the parking lot with the lower edge 4½ feet above the pavement. Space

[1] This article was presented at the 35th Annual Meeting of the Highway Research Board, Wash., D. C., Jan. 1956.

[2] *Analysis of certain variables related to sign legibility* by H. W. Case, J. L. Michael, G. E. Mount, and R. Brenner. Highway Research Board, Bulletin 60, 1952, pp. 44–58.

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Series C

Series E

Series ED

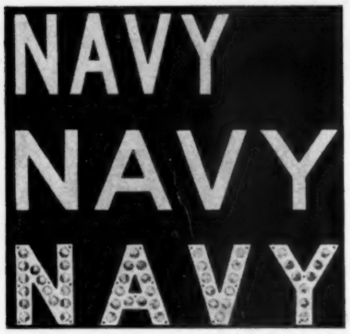


Figure 1.—Comparison of Series C, E, and ED alphabets at normal spacing.

was provided for two 4-letter words placed one above the other with a 10-inch clearance between lines. Individual letters 10 inches in height were combined to form the test words. Because individual letters were used on the panel, the spacing between letters could easily be varied to suit the requirements of each observation. Narrow guide strips were placed below the words to indicate the letter position for each test condition. The guide strips were not reflectorized or visible during the test runs.

Scope of Study

Three different alphabet designs were observed. Figure 1 shows the word NAVY displayed in each alphabet.

Series C and Series E alphabets, 10 inches in height, were chosen because they are representative of those commonly appearing on highway destination signs. These two alphabets were cut from reflective sheeting. The sheeting employed reflects nearly as much light at 20- or 30-degree angles of incidence as it does head on.

In a third alphabet, identified in this study as Series ED, 1¼-inch-diameter plastic reflectors formed the 10-inch high letters. The brightness of these units was considerably greater than the sheeting used for the Series C and E alphabets. The Series E alphabet was quite similar in form to the Series ED, which was designed by a manufacturer.

All three alphabets were made from materials with retrodirective properties; i. e., a tendency to reflect a large portion of the light back to the source regardless of the angle of the incident light. The sheeting from which Series C and E alphabets were cut is composed of minute glass spheres, while the plastic units used for the Series ED alphabet develop their reflection from the interior corners of cubes.

From each of the three alphabets, six test words were composed—BALK, FARM, NAVY, STOP, ZONE, and DUCK. These six words use 19 of 26 letters in the alphabet and have a variety of letter forms adjoining each other.

Each of the six words was displayed in three alphabet designs and four different spacings for each of the 36 observers. The base or normal spacing was determined by using the Bureau of Public Roads' spacing chart for Series C and E alphabets and the manufacturer's recommendations in the case of Series

Table 1.—Character (letter or numeral) width and normal spacing of 10-inch Series C and E standard alphabets and 10-inch Series ED (manufacturer's alphabet)

Character	Standard alphabets				Manufacturer's alphabet		
	Character width		Edge code [2]		Character width of series ED [3]	Margin spacing	
	Series C [1]	Series E [1]	Left	Right		Left	Right
	Inches	*Inches*			*Inches*	*Inches*	*Inches*
A	6.25	10.00	III	III	9.00	1.1	1.2
B	5.47	7.97	I	II	7.38	2.2	1.5
C	5.47	7.97	II	III	7.38	1.2	1.4
D	5.47	7.97	I	II	7.38	2.2	1.3
E	5.00	7.34	I	III	6.75	2.2	1.4
F	5.00	7.34	I	III	6.75	2.2	1.0
G	5.47	7.97	II	II	7.38	1.2	1.4
H	5.47	7.97	I	I	7.38	2.2	2.3
I	1.41	1.72	I	I	2.12	2.2	2.3
J	5.00	7.50	III	I	6.75	.8	2.3
K	5.47	8.12	I	III	7.62	2.2	.9
L	5.00	7.34	I	III	6.75	2.2	.9
M	6.48	9.22	I	I	8.50	2.2	2.3
N	5.47	7.97	I	I	7.38	2.2	2.3
O	5.78	8.28	II	II	7.62	1.2	1.3
P	5.47	7.97	I	II	7.38	2.2	1.3
Q	5.78	8.28	II	II	7.62	1.2	1.3
R	5.47	7.97	I	II	7.38	2.2	1.3
S	5.47	7.97	II	II	7.38	1.2	1.1
T	5.00	7.34	III	III	6.75	.9	1.0
U	5.47	7.97	I	I	7.38	2.2	2.3
V	6.09	9.06	III	III	8.12	1.1	1.2
W	7.50	10.47	III	III	9.38	1.1	1.2
X	5.86	8.59	III	III	7.62	1.1	1.2
Y	6.25	10.00	III	III	9.00	1.0	1.1
Z	5.47	7.97	III	III	7.38	2.0	2.1
1	2.03	2.97	I	I	3.12	2.0	2.3
2	5.47	7.97	II	II	7.38	1.2	1.1
3	5.47	7.97	III	II	7.38	1.3	1.5
4	6.09	9.22	III	III	8.25	1.2	2.0
5	5.47	7.97	I	II	7.38	1.1	1.2
6	5.47	7.97	II	II	7.38	1.3	1.2
7	5.47	7.97	III	III	7.38	.9	1.0
8	5.47	7.97	II	II	7.38	1.2	1.3
9	5.47	7.97	II	II	7.38	1.2	1.3
0	5.78	8.28	II	II	7.62	1.2	1.3

[1] Stroke width for Series C, 1.41 inches; Series E, 1.72 inches.
[2] Edge codes determined, with minor exceptions, as follows: Code I indicates side of character has vertical outline; code II, curved outline; and code III, diagonal or open-faced outline. For measurements and sample calculations, see tables 2-3.
[3] Stroke width for Series ED, 2.12 inches. Reflectors measure 1¼ inches in diameter.

ED. These values are shown in tables 1 and 2. A sample calculation for determining the length of a word with normal spacing is given in table 3. To increase interletter spacings, word lengths 20, 40, and 60 percent greater than normal were chosen and the individual letters were arranged within that length to produce a satisfactory appearance.

The 72 combinations of alphabets, words, and spacings were displayed on the panel two at a time. The two combinations used for each panel were changed at the halfway point in the test. In this manner, each combination of alphabet, word, and spacing appeared one-half of the time with a word and spacing combination from each of the other two alphabets. The panel displays were systematically chosen so that each word appeared two or three times with every other word. The order of panel presentation was initially selected at random for each half of the test runs, and then the order was advanced for each observer so that each alphabet, word, and spacing combination appeared about the same number of times near the beginning, middle, and end of the test sequences. Also, each combination was shown about the same number of times in the upper position on the panel as in the lower position.

In short, each combination of alphabet, word, and spacing received as favorable treatment as any other, and the 36 observers read the 72 combinations in conformance with a plan designed to minimize every foreseeable bias. This resulted in a total of 2,592 balanced observations.

In addition to the 72 combinations that were displayed two at a time, the 24 combinations of the Series E alphabet were displayed one at a time for 29 of the 36 observers. Only 6 of the 24 combinations were displayed for any single observer, however.

Figure 2 illustrates a partial breakdown of the 2,592 observations. For the 10-inch Series E alphabet, 216 of the 864 observations were made at each of four different word lengths. The same breakdown was used for Series C and ED alphabets. Similar procedures were followed for each succeeding subgrouping of the total observations.

Table 2.—Normal spacing between 10-inch letters of alphabets with combinations of codes I, II, and III for adjacent edges

Examples of letter combinations	Edge code combinations	Letter spacing [1]	
		Series C	Series E
		Inches	*Inches*
HI, JL	I-I	2.11	2.58
NO, PB	I-II or II-I		
NA, FL	I-III or III-I	1.69	2.06
GO, RC	II-II		
ST, ZO	II-III or III-II		
FT, LA, VY	III-III, not parallel.	1.12	1.37
EX, LT, WA	III-III, parallel.	.56	.68

[1] Measured horizontally between nearest points.

Table 3.—Sample calculation for determining length of the word NAVY in 10-inch letters of the Series E and ED alphabets with normal spacing

Letter	Width of letters	Edge code		Margin spacing		Combination of codes for adjacent edges	Spacing between letters	Length of word
		Left	Right	Left	Right			
Solution for Series E								
	Inches			*Inches*	*Inches*		*Inches*	*Inches*
N	7.97	I	I			I-III	2.06	
A	10.00	III	III			III-III, parallel	.68	
V	9.06	III	III			III-III, not parallel	1.37	
Y	10.00	III	III					
Total	37.03						4.11	41.14
Solution for Series ED								
N	7.38			2.2	2.3		3.4	
A	9.00			1.1	1.2		2.3	
V	8.12			1.1	1.2		2.2	
Y	9.00			1.0	1.1			
Total	33.50						7.9	41.4

Visual acuity for each observer was determined from his test results for all three alphabets and six words at normal spacing. The mean legibility distance for these 18 combinations was the visual acuity score for a given observer. All 36 observers were ranked according to their visual acuity scores and then divided into three visual acuity groups of 12 observers each. This grouping was used in analyzing the effect of visual acuity on legibility.

Conclusions

The following conclusions may be drawn for the nighttime legibility of 10-inch white reflectorized letters on a dark, nonreflectorized background under simulated roadway conditions, and with low beam of the headlamps:

1. Definite improvements in legibility result from moderate increases above the spacings normally used between sign letters. If interletter spacings are increased until the word length is 40 percent greater than normal, the mean legibility distance increases 15 percent above normal for the Series C alphabet, 16 percent for Series E, and 7 percent for Series ED.

2. An increase of approximately 40 percent over the normal word length is about the limit for realizing additional legibility through greater interletter spacing. Words lengthened more than 40 percent above normal gain little or nothing in legibility; with Series E and ED alphabets, word legibility actually declines and the increase with Series C is only slight.

3. Mean legibility distances recorded for the 36 observers were 478 feet for the Series C alphabet, 596 feet for Series E, and 614 feet for Series ED—all measured at normal letter spacing. The 15-percentile values ranged from 27 to 33 percent lower, being 350, 400, and 450 feet for Series C, E, and ED alphabets, respectively.

4. Words formed with the Series ED alphabet have slightly superior legibility in comparison with the Series E alphabet when word lengths are normal or no more than 10 percent in excess of normal. At wider letter spacings, the Series E alphabet is more legible. Letter design details and reflectent characteristics both differed between the Series E and ED alphabets, but an evaluation of the independent contributions of these two factors to legibility was beyond the scope of this study.

5. Legibility distances for words formed with the Series E alphabet are 118 to 142 feet greater than for Series C at the various spacings. The Series C alphabet, however, occupies less word length for a given spacing, and on the basis of legibility distance per inch of word length, it is somewhat superior to Series E. The two alphabets are equally legible when displayed at corresponding spacings and when letters of the Series E alphabet are reduced in height so that the legend areas are the same.

6. A display of two words rather than one on a sign tends to reduce the distance at which any single element of the message is legible. Additional words on the sign would reduce legibility further.

7. The responses of observers grouped according to their visual acuity are similar. Legibility curves determined for these groups,

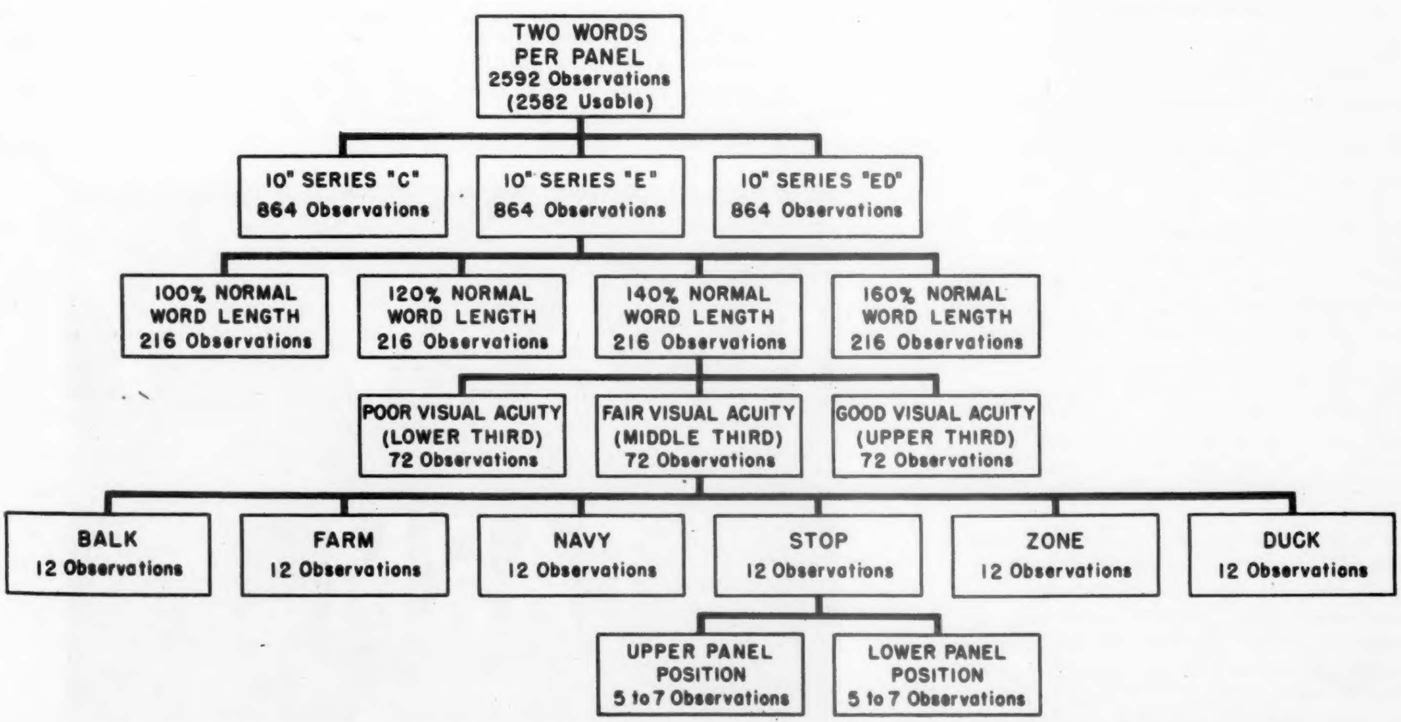


Figure 2.—Number of observations for each alphabet, spacing, visual acuity group, word, and panel position.

Figure 3.—Appearance of sign panel from a distance of 200 feet.

though of a different magnitude, follow remarkably consistent patterns.

8. A change from 5 to 7 feet in the vertical position of a sign legend above the roadway has little effect on the legibility distance.

9. More consideration of sign proportions is warranted in the development of sign design. Where vertical dimensions are restricted and dictate the use of letter heights less than those desirable, increased word lengths can help to compensate for the loss of legibility distance that would otherwise occur.

10. Within the limitations of appearance and need for emphasis, the horizontal spacings between sign letters should more commonly be increased to take advantage of portions of the sign area otherwise unused.

Test Procedure

Each observer was instructed to drive along the course at an estimated speed of 30 miles per hour, but to focus his attention on the sign panel rather than on the speedometer. He was shown a typewritten list of the six test words before the test began, but was not informed of their order of presentation or about details of alphabet and spacing. Normally, two cars made test runs in close sequence—beginning at one end of the course some 1,500 feet from the sign panel. The first driver was allowed to proceed 600 to 900 feet along the course before the second driver started in order to minimize interference in the legibility observations. The driver made the observations and a recorder sat in the rear seat. No one else was in the car and all runs were made using low beam of the headlamps.

As soon as the driver-observer could read either of the two words, he called it aloud, and the recorder noted the distance from the panel to the nearest 25 feet by referencing his position to coded markings on the course. Similarly, the second word was read as soon as legible and the distance recorded. After both words had been read, the observers continued past the sign panel and drove back to the beginning of the course. Two new words were then placed on the panel. During each circuit of the course, which consumed about 2½ minutes, each observer usually saw the headlamps of the other car although not while actually reading the signs. Thus the effect of light from intermittent opposing headlamps on the eye was introduced to a limited extent, but care was taken to avoid any direct glare.

Observers were instructed to drive so that the left edge of the car was in line with a row of parking stall markings. This resulted in a simulated vehicle placement in the center of a 12-foot lane with the near edge of the sign panel 6 feet from the right shoulder.

The instructions discouraged guessing by observers and few combinations were read incorrectly. At times it was possible to expose the incorrectly read combinations for a second observation, and as a result only 10 observations of the 2,592 were not usable.

Figure 3 shows the words NAVY and FARM from the observer position in a car 200 feet from the sign panel. The stall markings that served as a guide for the observers are dimly visible at the left. Beside the left curb, coded course markers spaced 50 feet apart were used by the recorder to identify the point at which the observer read each combination.

Figure 4 is a closeup view of the panel. NAVY is formed with letters of the Series ED alphabet at the widest spacing (word length, 60 percent greater than normal). FARM is formed using letters of the Series C alphabet at normal spacing.

Legibility Distances Determined

For each of the 36 observers, an average legibility distance was calculated from all 72 observations. These values varied from less than 300 to nearly 900 feet, a ratio of over three to one. Figure 5 shows this relation. Over two-thirds of the observers had average values between 500 and 800 feet, but the distribution was somewhat skewed in the lower direction with one-ninth of the observers having average distances below 400 feet. When highway signs are designed, the capabilities of drivers with poor visual acuity deserve special consideration. Observers wearing glasses did not perform quite as well as a group as those without glasses.

Word lengths increased

For all three alphabets, increasing the spacing first produced greater legibility, then a leveling off or an actual decrease in legibility occurred, as shown by figure 6.

The mean legibility distance for the narrow Series C alphabet at normal spacing was 478 feet. Legibility increased to 549 feet at word lengths 40 percent greater than normal, but the 60-percent increase in word length resulted in only 5 feet more of legibility distance.

The wider Series E alphabet produced a mean legibility distance of 596 feet at normal spacing. A 40-percent increase in word length resulted in a mean legibility distance of 691 feet, while the 60-percent increase in word length actually reduced the legibility distance by 10 feet.

For the Series ED alphabet, similar in form

Figure 4.—Closeup view of the sign panel.

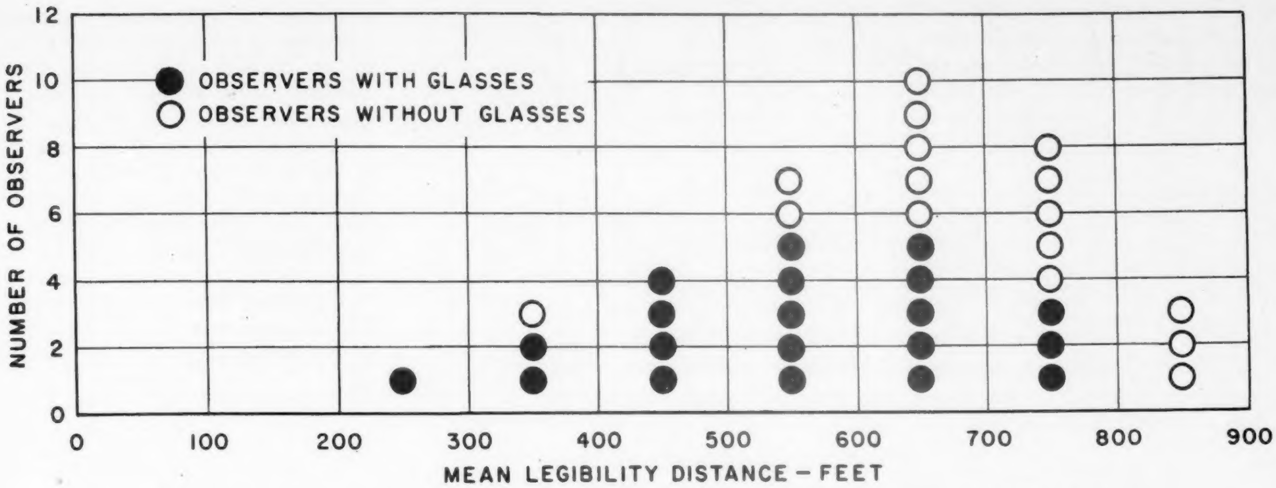


Figure 5.—Observations of 36 observers distributed according to the mean legibility distances.

to the Series E but of a different reflectorizing material, the mean legibility distance was 614 feet at normal spacing. Legibility increased to 657 feet at word lengths 40 percent greater than normal, but the 60-percent increase in word length resulted in a 13-foot decrease in the mean legibility distance.

As figure 6 clearly shows, Series E and Series ED alphabets should not be displayed at word lengths that are much more than 40 percent greater than normal, for at these wider spacings an actual decrease in legibility resulted. Little was gained by displaying the Series C alphabet at spacings beyond the 40-percent point.

The percentage increases in legibility with increased spacing were nearly identical for Series C and Series E alphabets, as shown by figure 7. An increase in word length of 40 percent over normal increased legibility 15 percent for Series C, and 16 percent for Series E, but only 7 percent for Series ED.

Effect of visual acuity

As noted earlier, highway signs should be designed for the driver with poor vision rather than for the average driver. The data were analyzed to determine whether drivers with poor, fair, and good eyesight showed similar and proportionate changes in their legibility patterns as letter spacings were increased.

Figure 8 shows mean legibility distances for each of the three visual acuity groups. In the case of the Series C alphabet, mean legibility distances for the poor visual acuity group were at least 250 feet below those of the good visual acuity group. For Series E and Series ED alphabets, the differences between the poor visual acuity group and the good group were over 300 feet. In general the patterns of legibility were similar for all groups.

These relations are shown on a percentage basis in figure 9. A 40-percent increase in word length resulted in a 12-percent increase in legibility of the Series C alphabet for the poor visual acuity group, 19 percent for the fair group, and 13 percent for the good group. For the Series E alphabet, percentage increases for the three groups were 17, 13, and 18 percent, respectively; while for Series ED the percentages were 6, 9, and 5 percent, respectively. The poor visual acuity group was within one percent of the average value for all three groups combined for Series E and ED alphabets, and within 3 percent for Series C. Because of this close agreement and the fact that relative values only are of principal importance in much of this study, the three groups were combined for most of the analysis.

After combining all visual acuity groups, the lower 15-percentile legibility distances at normal spacing were 350 feet for Series C, 400 feet for Series E, and 450 feet for Series ED. This compared closely with the mean legibility distances for the poor visual acuity group of 351, 414, and 449 feet, respectively.

One and two words per panel compared

When two words are placed on a single panel, each can have some effect on the legibility of the other. The 174 observations of words formed with the Series E alphabet and placed on the panel one at a time give a general indication of this effect, as shown by figure 10. The number of observations of "one word per panel" for a given visual acuity group and spacing was not the same. To correct for this, equal weight was given to each visual acuity group and spacing regardless of the number of observations within each category.

As the corrected curve in figure 10 shows, observations made with only one word per panel resulted in legibility distances ranging from 46 to 123 feet greater than for two words per panel. When only one word at a time was displayed, legibility showed a more rapid gain as spacing was increased, and continued to improve beyond the 40-percent increase in word length.

Legibility of six test words varies

Of the six words tested, STOP was consistently read at the greatest distance. Undoubtedly, this was due in part to the familiarity of this word to the average driver because of its use on the standard STOP sign. In addition, the letters are so arranged that a rather distinctive open shape results.

In the case of the Series C alphabet, BALK

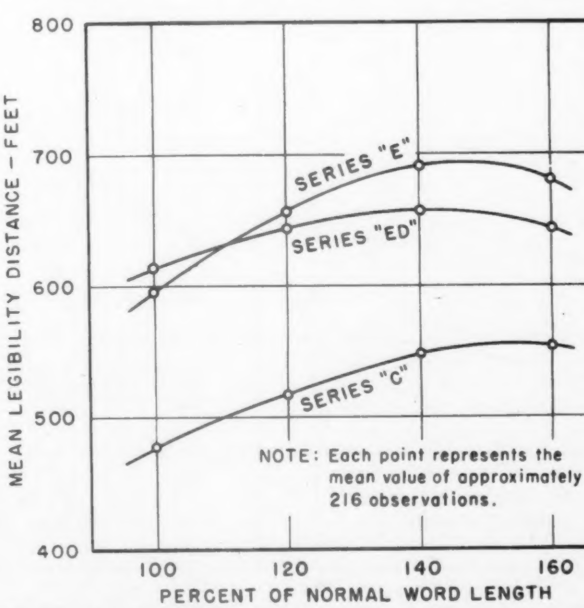


Figure 6.—Legibility distances for Series C, E, and ED alphabets as affected by the spacing between letters in test words.

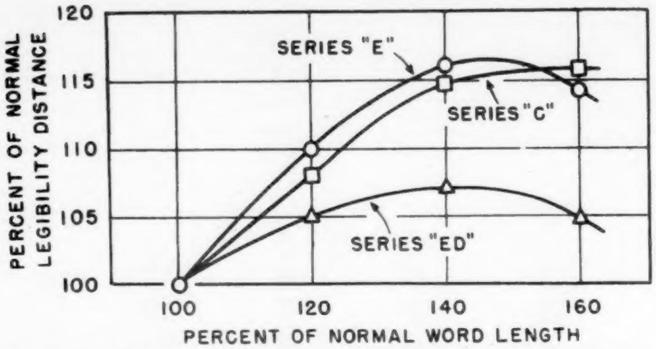


Figure 7.—Percentage change in legibility distances for Series C, E, and ED alphabets as affected by the spacing between letters in test words.

was the least legible at all spacings. The remaining words had about the same legibility, with DUCK slightly below the rest as shown in table 4. DUCK and BALK have somewhat similar shapes and the difficulty of distinguishing between them may have accounted for their diminished legibility. BALK was also near the bottom in legibility for both Series E and Series ED alphabets as shown in the table, while DUCK was slightly above average for Series E and slightly below average for Series ED.

Figure 11 shows the percentage increase in legibility of individual words with an increase in word length. The Series C alphabet had the most consistent pattern for the six words and Series ED, the most erratic pattern; the word FARM in letters of the Series ED alphabet actually showed a decrease in legibility as spacing increased.

Effect of panel position

The upper or lower position on the panel had little effect on legibility as shown by figure 12. Series C and E alphabets were both more legible when placed on the lower portion of the panel, approximately 5 feet above the roadway surface. The Series ED alphabet was more legible in the upper position, which was roughly 7 feet above the roadway surface. The average difference in legibility was generally less than 20 feet for any one of the three alphabet series, and has no significant implications for sign designers.

A possible explanation for the difference in legibility of words in the two panel positions is that the Series ED alphabet is made from a material with greater apparent reflectance than optimum for the low-beam illumination and other conditions of the test, while Series C and Series E alphabets are made from materials with less apparent reflectance than the optimum. Thus the upper panel position for the Series ED alphabet may in this case be better than the lower one because it receives less incident light from the headlamps and the apparent reflectance is less. With Series C and Series E alphabets the converse applies.

Comparison of Series E and ED Alphabets

One of the more interesting comparisons made involves the relative legibility values obtained with the Series E and ED alphabets. These were of similar design, except that the Series E alphabet was cut from reflective sheeting, and Series ED was constructed of plastic reflector units. As figure 6 and table 4 show, at normal spacing the Series ED alphabet was legible 18 feet farther than the Series E, while at word lengths 20 percent greater than normal, the legibility distance for Series ED was 10 feet less than Series E, and at word lengths 40 and 60 percent above normal, the legibility distances for Series ED were 34 and 37 feet less, respectively.

A characteristic of the letter design in the Series ED alphabet is that it results in slightly

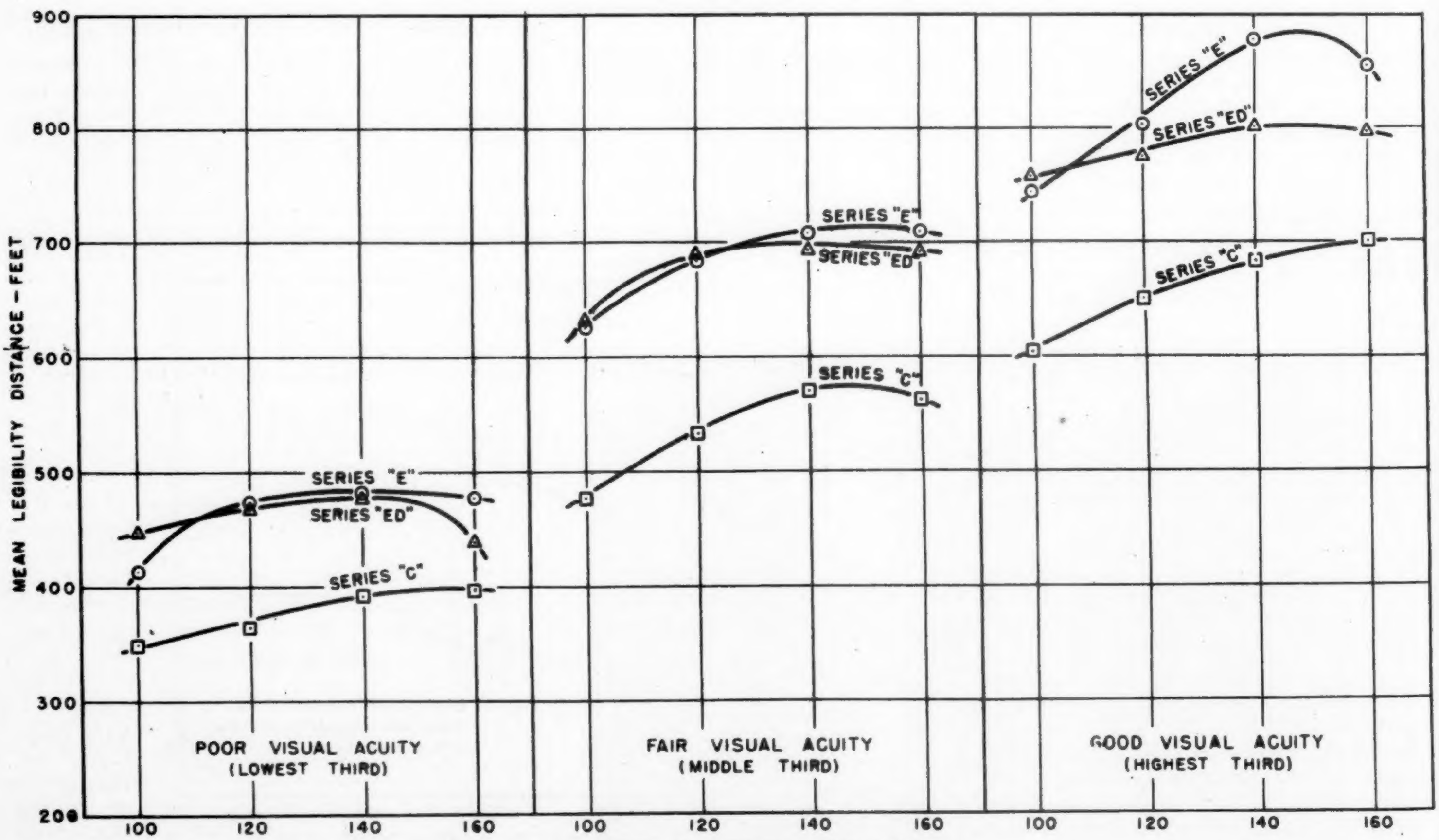


Figure 8.—Legibility distances, according to visual acuity groups, for Series C, E, and ED alphabets as affected by the spacing between letters in test words.

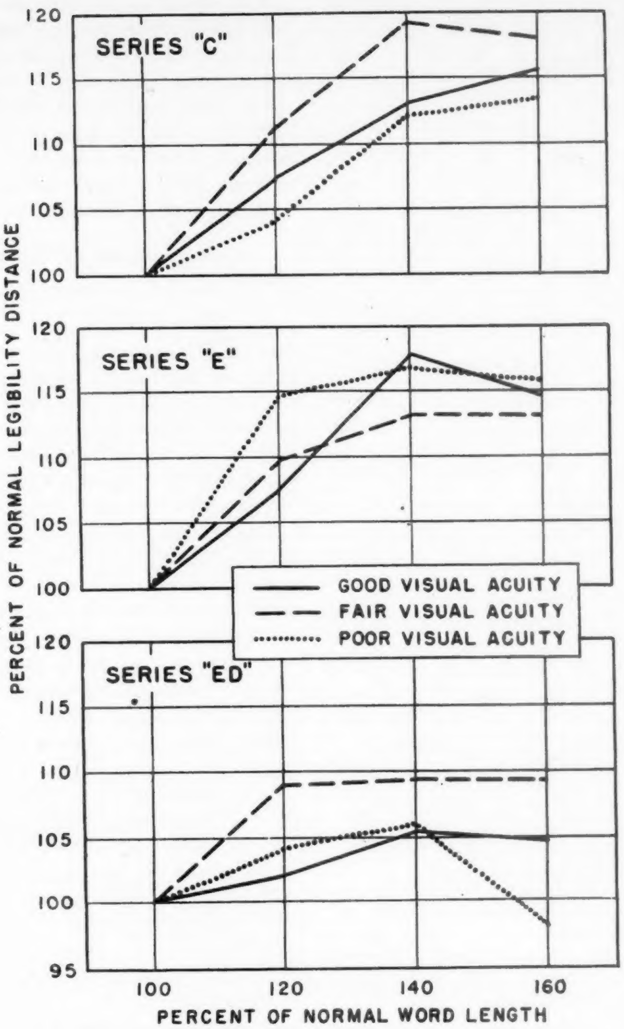


Figure 9 (Left).—Percentage change in legibility distances, according to visual acuity groups, for Series C, E, and ED alphabets as affected by the spacing between letters in test words.

greater word lengths than those of standard Series E. Figure 13 shows the mean legibility distance expressed in terms of feet of legibility distance per inch of word length. This tends to equalize the minor differences in word length between the two alphabets. Again the Series ED alphabet is superior at normal spacing and Series E at the wider spacings. The highest values, obtained with the Series C alphabet, are discussed later.

In the final analysis, the most useful value for comparative purposes is the height of letters of the Series E alphabet that results in a legend area per letter equal to Series ED at each of the four spacings. In order to obtain this, it was first necessary to know how the legibility of Series E changed with letter height.

A study reported by Forbes et al.[3] contains data that make possible this determination. That study used a white Series E alphabet on a black background. Night observations were made by individuals on foot and the signs were artificially illuminated. The spacing between letters was greater than the normal spacing of the present study and, in addition, the stroke width was about 16 percent greater than the standard. If the six words used in the present study had been similarly composed, the word lengths would have been 11 percent greater than normal.

The median legibility distances for 8- and 12-inch capital letters forming "place names with knowledge" were 690 feet and 1,060 feet, respectively. Thus, in this range of letter height, each inch increased the legibility distance an average of 92½ feet, and the calculated legibility of a 10-inch letter is 875 feet. In the present study, the corresponding median value was 640 feet, and the mean legibility distance was 630 feet.

The differences in results arise from several factors, principal among which are the driving observers, the display of two words per panel, and perception-reaction requirements. These factors are additive in their effect and help to account for the differences in legibility distances recorded. Because the results of these parallel studies are reasonably comparable, it is feasible to demonstrate the relative effects that letter height and spacing have on sign design.

The incremental value of 92½ feet per inch of letter height was derived from a word length 11 percent greater than normal in the present study. Proportionate ratios were computed for other word lengths, and these ratios were used to determine mean legibility distances of words formed with the Series E alphabet and measuring above and below 10 inches in height.

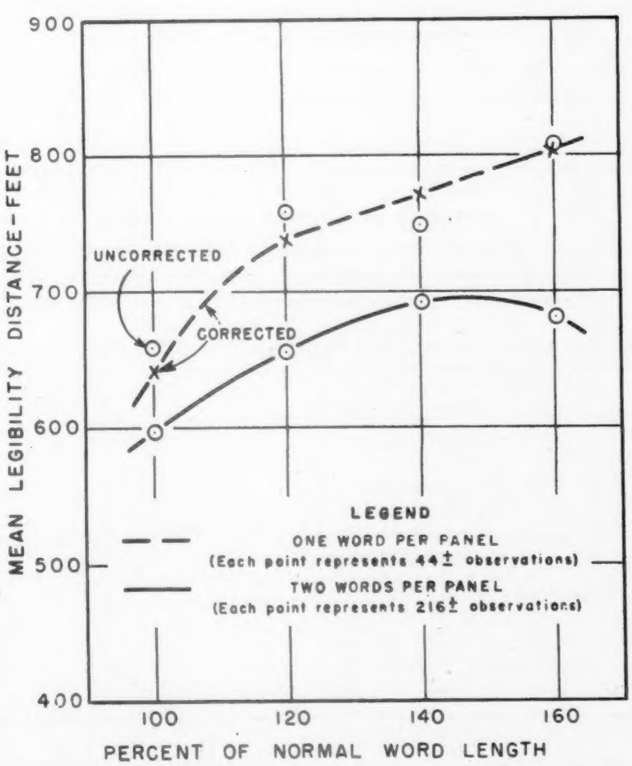


Figure 10.—Legibility distances, according to the number of words displayed on panel, for Series E alphabet as affected by the spacing between letters in test words.

[3] *A comparison of lower case and capital letters for highway signs* by T. W. Forbes, Karl Moskowitz, and Glen Morgan. Proceedings of the Highway Research Board, vol. 30, 1950, pp. 355–373.

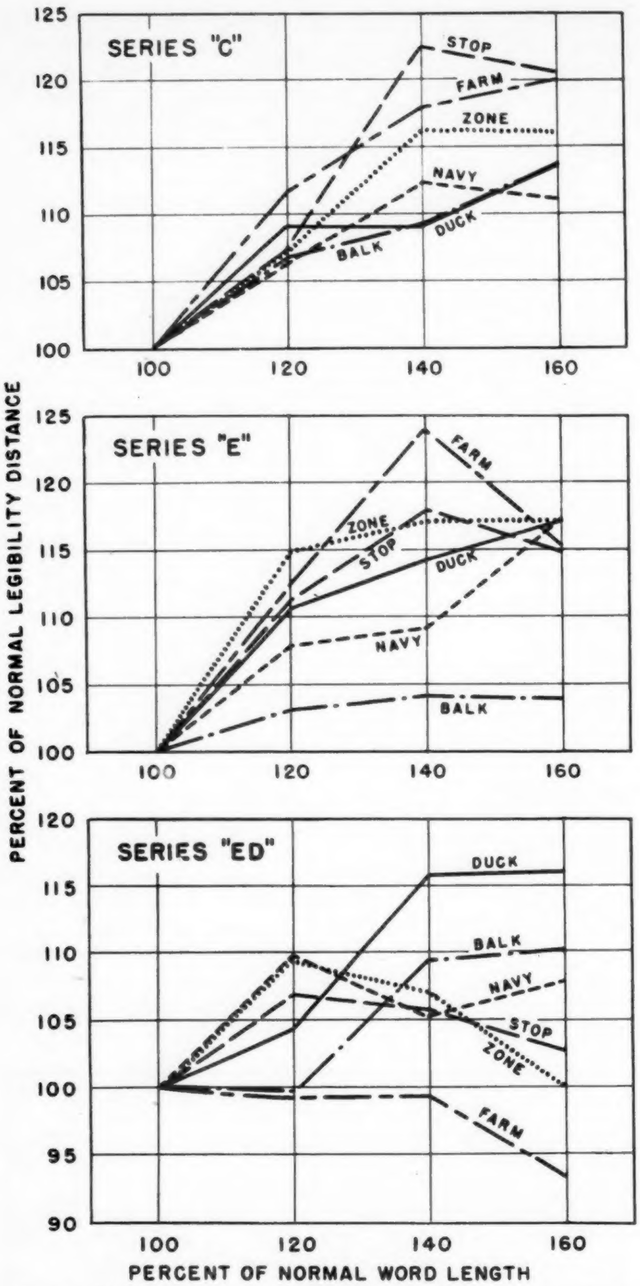


Figure 11.—Percentage change in legibility distances for each test word of Series C, E, and ED alphabets, as affected by the spacing between letters in test words.

For equal legend area per letter, a 10.05-inch letter of the Series E alphabet is equivalent to a 10-inch letter of the Series ED alphabet at corresponding spacings. At normal spacing the legibility of the 10-inch Series ED alphabet is 14 feet greater than the 10.05-inch Series E, while at word lengths 20, 40, and 60 percent greater than normal, the Series ED alphabet has 15, 39, and 42 feet less legibility.

Comparison of Series C and E Alphabets

As figure 6 shows, the Series E alphabet has an advantage over Series C of between 118 and 142 feet in legibility distance at the various spacings. The Series E alphabet occupies considerably more sign area, however, and if mean legibility distance per inch of word length is considered, Series C has the advantage as shown by figure 13.

Of greater interest, perhaps, is the resulting legibility when the two alphabets occupy equal legend area per letter and are displayed at the same relative spacing. A letter of the Series E alphabet, 8.34 inches high, occupies the same legend area as a 10-inch letter of the Series C alphabet at corresponding spacings. The mean legibility distances for the 8.34-inch letter height were calculated using the procedure outlined earlier.

The results of this calculation are shown in figure 14. It is seen that the Series C alphabet has an advantage over the Series E when legend area is taken into account. The differences are small, however, and since the curves were derived from two separate studies, a fairer statement would be that Series C and Series E alphabets are equally efficient users of sign space.

In a recent revision of the Manual on Uniform Traffic Control Devices,[4] it was recommended that the letters of the narrower Series A and B alphabets not be used for reflectorized signs. The present study, however, indicates that Series C, next in width, has no disadvantage when compared with the wider Series E alphabet. It is conceivable, therefore, that at least for night legibility of white reflectorized letters on a dark background, letters even narrower than Series C

[4] *Revisions to the manual on uniform traffic control devices for streets and highways*, Bureau of Public Roads, 1954, p. 1.

Table 4.—Legibility distances for Series C, E, and ED alphabets as affected by the spacing between letters in test words

Test word	Mean legibility distance—feet														
	Series C alphabet					Series E alphabet					Series ED alphabet				
	Normal word length	Word length increased by— 20 percent	Word length increased by— 40 percent	Word length increased by— 60 percent	Average, all word lengths	Normal word length	Word length increased by— 20 percent	Word length increased by— 40 percent	Word length increased by— 60 percent	Average, all word lengths	Normal word length	Word length increased by— 20 percent	Word length increased by— 40 percent	Word length increased by— 60 percent	Average, all word lengths
STOP	526	564	644	634	592	638	710	753	734	709	661	706	699	680	686
NAVY	487	519	547	541	523	602	649	716	706	668	622	682	655	670	657
ZONE	480	515	559	558	528	568	651	666	666	638	629	689	674	629	655
DUCK	470	512	512	534	507	596	659	682	698	659	576	601	666	669	628
FARM	465	519	549	557	522	576	648	712	665	650	616	611	612	575	603
BALK	442	471	484	502	475	595	614	620	619	612	579	578	634	639	607
Average	478	517	549	554	---	596	655	691	681	---	614	645	657	644	---

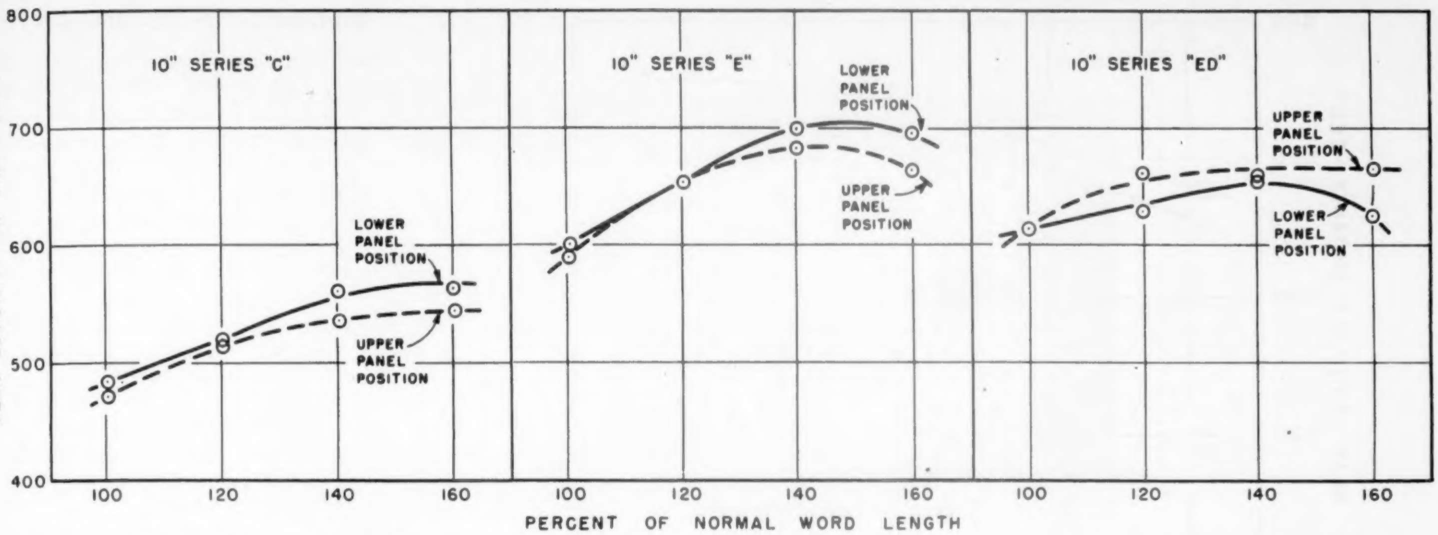


Figure 12.—Legibility distances, according to panel position, for Series C, E, and ED alphabets as affected by the spacing between letters in test words.

may also be as efficient as Series E. This finding may or may not hold for daytime viewing.

The effect of irradiation or spreading of the stroke width of white reflectorized letters may account for the close agreement in legibility of the 10-inch Series C and 8.34-inch Series E alphabets. A narrower stroke width for Series E might produce improved night legibility.

To obtain with letters of the Series C alphabet a legibility distance equivalent to that of Series E at comparable spacings, a greater letter height must be used. Words formed with the 10-inch Series C alphabet are only about as legible as those formed with the 8½-inch Series E alphabet. The legibility equivalent of a 10-inch Series E alphabet would be a Series C alphabet about 12 inches high. An obvious feature of this relation is the saving in the vertical dimension of a sign where short, wide letters are used in place of tall, narrow letters.

Alternative Methods of Improving Legibility

It has been shown that for a given alphabet, additional spacing between letters will increase legibility. The question still remains, however, as to whether legibility should be increased in this fashion or by increasing the letter height.

Again by use of the data contained in the Forbes study,[5] it is possible to compare the two alternatives, as in figure 15. Here it may be seen that a word, formed with 10-inch letters of the Series E alphabet with spacing 20 percent greater than normal, occupies about the same legend area per letter as a word with 11-inch letters at normal spacing, but gives slightly less legibility. An increase of 40 percent in word length increases the legibility distance somewhat less in proportion to that attainable by increasing the letter height. Beyond 40 percent, of course, legibility declines rapidly; thus the use of these wider letter spacings is undesirable.

In general, it is desirable that the initial sign layout be made at normal spacing, using the width of alphabet and letter height required for the legibility desired. In the development of a final design, the opportunity to introduce additional interletter spacing can often be used to advantage. Where two or more lines of sign copy are to be used, one line seldom fills the entire sign width. Increased spacing may be used for this line, thus increasing legibility with no increase in the size of sign panel required. For signs on overhead structures or for overhead signs at other locations, the vertical dimension of the sign may be limited and a comparatively small letter height may be required. In such instances, the common practice has been to shrink the total dimensions. Actually, the widest practicable alphabet (Series E or even the widest standard alphabet, Series F) and up to 40 percent more word length can be utilized to good advantage. Similarly, where the horizontal sign dimensions are restricted, letters of the narrower Series C alphabet can be employed at normal spacing, and legibility increased by using a greater letter height.

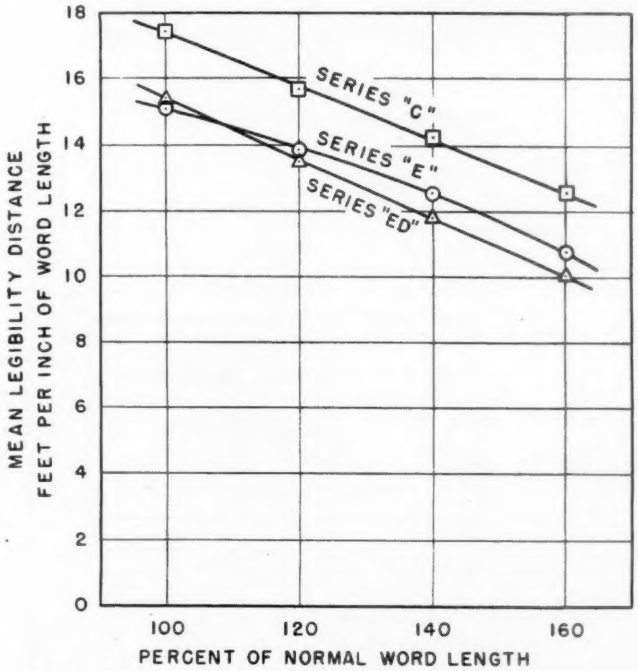


Figure 13.—Legibility distances (in feet per inch of word length) for Series C, E, and ED alphabets as affected by the spacing between letters in test words.

[5] See footnote 3, p. 7.

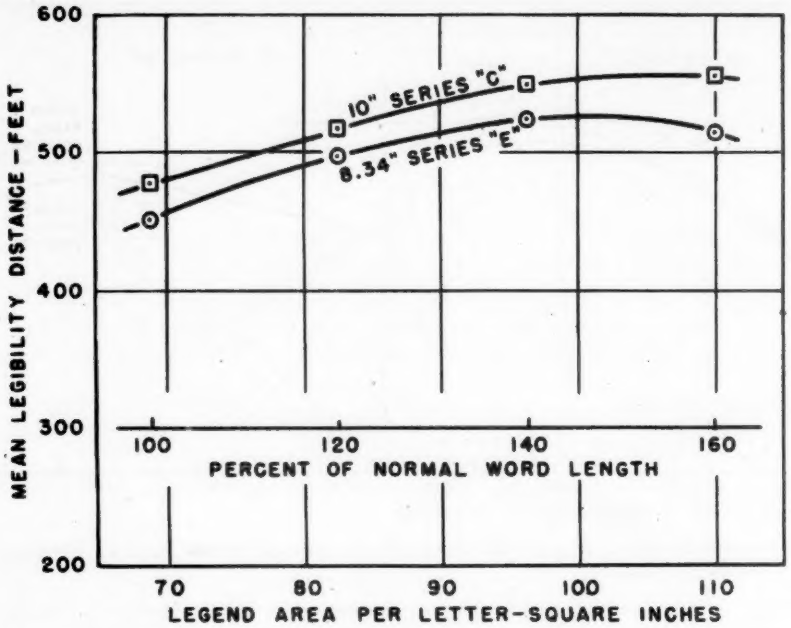


Figure 14.—Legibility distances for Series C and E alphabets (letters adjusted in height to produce equal legend areas) as affected by the spacing between letters in test words.

Application of Test Results

A sign found near many cities having large airports is AIRPORT, NEXT RIGHT. Figure 16 shows a possible design for such a sign. Series C and E alphabets are used with letters 12 inches high and normally spaced. These would probably be the desired proportions under normal conditions for a ground sign where adequate distance is available for advance warning and the average running speed is about 50 miles per hour.

With expressways handling heavy volumes of traffic, overhead signs are often necessary. Vertical clearances might be restricted if the sign were placed on an overhead structure. In that event, the sign could be stretched out as shown in figure 17. The vertical dimension then is reduced from 4 to 3 feet, and the horizontal dimension increased from 8 to 10 feet.

AIRPORT is comprised of letters of the Series F alphabet, 10 inches high, and the spacing is increased so that the word length is 40 percent greater than normal. This results in a word that has substantially the same legibility as the ground sign, which had 12-inch letters of the Series E alphabet and normal spacing. Similarly, NEXT RIGHT uses 10-inch letters of the Series E alphabet at a word length 20 percent greater than normal. The resulting legibility is better than could be obtained from the ground sign, which had 12-inch letters of the Series C alphabet and normal spacing.

Figure 15 (Below).—Legibility distances for Series E alphabet as affected by the height of letters and the spacing between letters in test words.

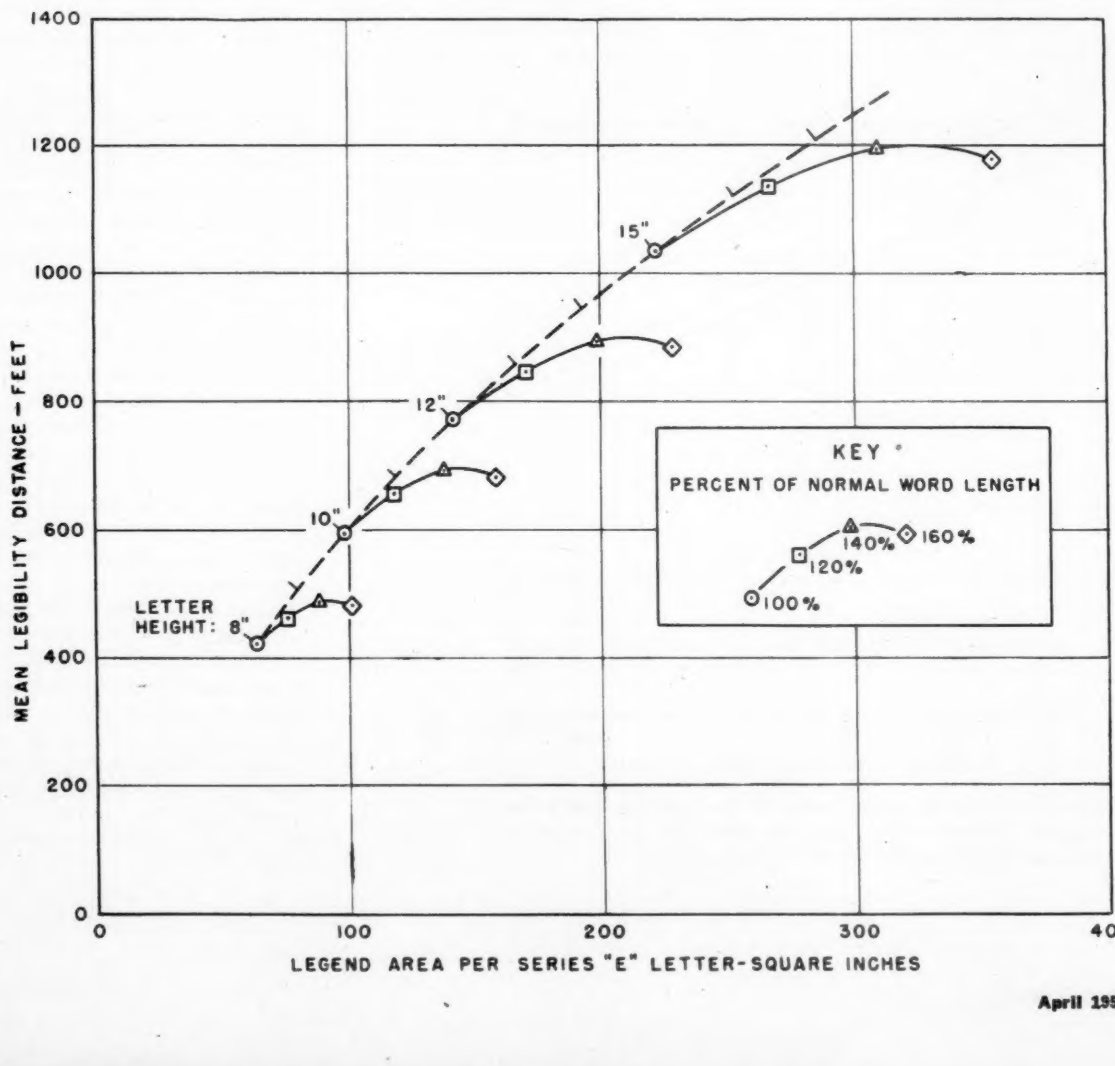


Figure 16.—Typical ground sign with 12-inch letters and normal spacing.

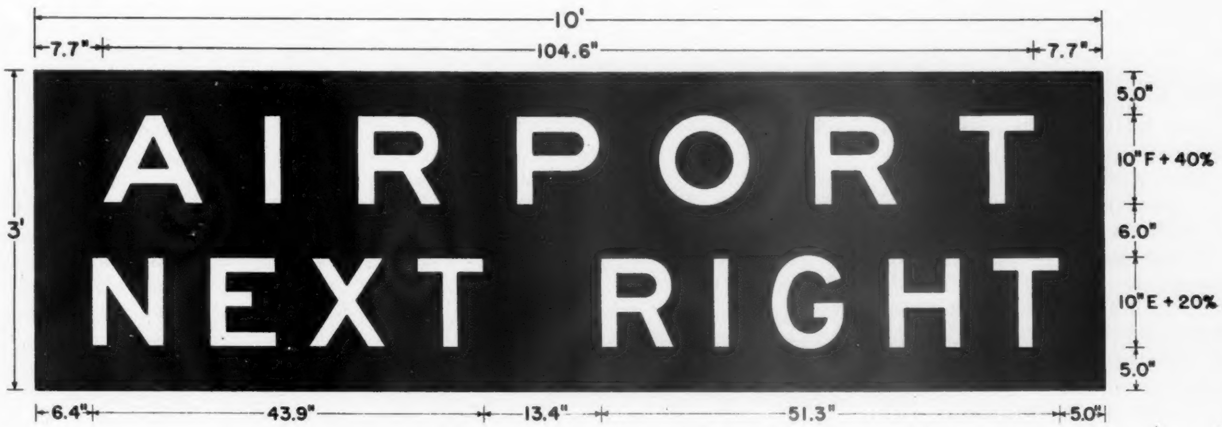


Figure 17.—Overhead sign with 10-inch letters and extended spacing.

New Publication

The Bureau's HIGHWAY STATISTICS, 1954, the tenth of the bulletin series presenting annual statistical and analytical tables of general interest on the subjects of motor fuel, motor vehicles, highway-user taxation, financing of highways, and highway mileage is now available.

The 135-page publication may be purchased from the Superintendent of Documents, Government Printing Office, Washington 25, D. C., at 75 cents a copy. The series of the annual bulletins that are available from the Superintendent of Documents are indicated on the inside back cover of Public Roads.

Tomorrow's Highways Depend Upon Today's Law

By DAVID R. LEVIN [1]
Chief, Land Studies Section
Bureau of Public Roads

IT bids well for the Nation that women are becoming seriously interested in better and safer highways, and want to do something about it. A tenacity of purpose and a never-ending dedication to an ideal have always characterized such an interest. These very sessions on traffic safety provide the evidence.

A new era is emerging in highway history. It might be called the era of modernization. Unprecedented traffic volumes, increasing urbanization, and the rapidly mounting inadequacy of the highway plant compel consideration by all States and localities of the need for large-scale highway improvement.

Highway modernization is not accomplished by magic. Financial resources must be provided to do the job. Engineering and administrative talent must be enlisted to bring the latest technological advances to bear on the problem. Finally, we must provide the very best laws to support all of these efforts. In fact, unless we have the best legal tools we can forge, the public official will be powerless to improve the safety of our highways.

Many of the laws under which State and local highway officials now have to work are of the horse-and-buggy vintage. In the highway field, we are still trying to fly a jet plane with a "Model T" motor. It just can't be done without frightful consequences, many of which have already been enumerated for you by previous speakers.

Let me give you a few illustrations of what I'm talking about. While the most qualified engineering opinion points to the expressway (with control of access) as the best single answer to moving large volumes of vehicular traffic safely and efficiently, five States still have no specific statutory authorization for control of access. Many of the remaining States which do have laws on this subject have only inadequate authorizations.

Even isolated parcels of land needed for highway right-of-way purposes can effectively block construction progress. In such instances, it is in the public interest for public authority to have the right of immediate possession, with full protection of the property owner's rights to just compensation. Yet even today, almost one-half of the States are unable to obtain possession of highway rights-of-way when the need is greatest.

In some States, there remain in full force and effect on the statute books such prize specimens as the provision for a fine of $25 for the offense of leaving horses attached to a carriage carrying passengers for hire, and for not leaving the reins in the hands of some person to prevent the horses from running away.

The chief counsel of the Michigan State Highway Department and the assistant attorney general of that State recently reported that, of some 1,000 provisions of law relating to highways (a number of which date back to 1883), roughly one-third of them are obsolete, outmoded, in conflict with subsequent legislation, and are otherwise meaningless. Under such circumstances even the most able lawyers disagree as to what is the law. Little wonder that the highway engineer becomes concerned when he is sincerely trying to build a highway system.

Extensive modernization of the highway plant may mean that houses and other structures which are found within the proposed right-of-way limits must be moved or demolished, and that appropriate accommodations must be found for the occupants. This is particularly true in the urbanized areas, where modernization of highways is most critically needed. Yet the State laws designating procedures for rehousing and tenant relocation are found only in a few States.

Because of the rapid increase in the number and use of motor vehicles in the United States, right-of-way widths which were adequate yesterday are obsolete today. Yet a number of State laws—some of them in the Eastern States—specify that highway right-of-way width cannot exceed a designated amount; a width that was adequate for a transportation era that has long passed.

A number of States have evolved long-range highway programs; some of which stretch over a period of 10, 12, 15 years, and longer. The Congress of the United States, even now, has before it some important proposals for an accelerated highway program to take place over the next 10, 12, or 15 years. In all of these long-range programs, it is essential that the lands and property, which will be needed for the entire system, be acquired considerably in advance of need. A review of the highway laws in force today reveals that only 14 States can acquire lands for future use, and many of these laws are not entirely adequate. Incidentally, enormous savings are possible in programs of advance land acquisition. The California Division of Highways has estimated that it can save from $7 to $30 in the next 12 years for every dollar it invests today in highway rights-of-way needed for the future.

I could go on and on painting a darker picture with each additional illustration. But lest we become too discouraged, let me hasten to add that there is now sufficient reason to believe that the highway laws situation is going to improve, and rapidly.

In order to cope with this situation, the American Association of State Highway Officials has asked the Highway Research Board to set up a highway laws research project. A staff of five attorneys and three stenographers are engaged on this project. Incidentally, I am very happy to tell you that one of the five lawyers is a very brilliant woman.

The project is to take approximately 3 years to complete. The objectives of the study are twofold: (1) To ascertain, assemble, and analyze all existing State highway law in terms of logical, functional characteristics; and (2) with this background of fact, to isolate and determine what the important elements are of the laws in each functional category.

When this project is completed, we will know, with respect to traffic engineering or highway system classification, for example, what the laws of the 48 States now contain, and what the substantive elements are that should characterize any adequate statutory authorization in these fields. The same will be done for highway construction, land acquisition, maintenance, financing, drainage, and a host of other matters directly relating to highway development.

From this project and subsequent discussions there should finally emerge a cross section of the best thinking and experience as to what constitutes the basic elements in every functional phase of highway law. For the first time, there will have been developed a set of basic principles, which, by common consent, are deemed essential for adequate highway laws. With such practical yardsticks, every State will readily be able to evaluate its own body of laws in the light of present and future needs.

Now the all important question! What can you do to help? You can help a great deal. You constitute an important and articulate segment of the American public. As such, you can help tremendously by seeing to it that the highways in your community, county, and State are improved consistent with a sound, long-range plan. The program should be financed by a well-conceived fiscal policy and executed through highway laws that will help—not hinder—your highway officials who are trying desperately to do a job in the public interest.

Such an approach involves comprehensive factfinding to determine physical needs, fiscal requirements, and weaknesses in the highway law. You can help to generate interest in such investigations where needed. After they have been made, you can support the recommended findings with the same enthusiasm and vigor that has characterized your past program. The Committee on Highway Laws of the Highway Research Board will be pleased to make available to you the results of all of its research studies as they emerge.

[1] This address was presented at the January 23, 1956, meeting of The General Federation of Women's Clubs, Eastern Region, Traffic Safety Forum, New York City.

Sawed Joints in Portland Cement Concrete Pavements, Progress and Problems

BY THE CONSTRUCTION BRANCH
BUREAU OF PUBLIC ROADS

Reported [1] by EDWIN J. COPPAGE, JR., Chief, Construction Management Section

SINCE the earliest days of concrete paving, joints have been formed in the plastic concrete by various means. Recently there has developed a new practice of cutting joints in the hardened concrete by means of special sawing equipment of various makes utilizing diamond or silicon carbide blades or discs. The cut is made only part way through the slab, creating a weakened plane which subsequently cracks through the full depth of the slab.

Purpose of Sawing Joints

The purpose of experimenting with sawed joints was to find a type of joint that would be smoother riding and less subject to spalling than the customary formed joints. Considerable difficulty had been experienced in many States in obtaining consistently good results with formed joints. The various processes employed to create a weakened plane, such as inserting and removing a steel bar and the hand tooling of the joints, apparently disturbed the plastic concrete in a way that weakened it and caused subsequent spalling. Also the finishing process often resulted in elevating the concrete slightly, creating bumps at the joints. The quality of a formed joint depends largely upon the skill of the workman making the joint. In contrast the sawed joint appears to have overcome these shortcomings even when the work is done by novices.

Spread of Experimentation

In the past 5 years the practice of sawing joints has spread rapidly over the country until at least 28 States have tried it and with minor exceptions have found the new practice to their liking. Sawed joints have been tried with apparent success upon a variety of pavement designs both reinforced and plain with slab lengths from 15 to 100 feet, both with and without load transfer devices of various designs. Kansas was the first State to make widespread use of sawed joints and was the first State to develop standard specifications. Relatively few other States have had sufficiently varied sawing experience to warrant the drafting of standard specifications.

Construction Problems

While sawed joints appeared to eliminate the spalling and roughness often associated with formed joints, they created new construction problems. It became apparent in the early sawed-joint projects that random transverse cracks were likely to occur unless so-called "control" joints or relief joints were either formed at intervals of 60 to 100 feet or sawed at an early age. Kansas initially elected to use formed control joints at 80 to 100 feet, thereby eliminating the problem of early sawing. With wet-earth curing to reduce shrinkage and 20-foot reinforced slab design, Kansas experienced no cracking between the formed control joints up to 30 days. Other States sawed intermediate joints at various times and little or no uncontrolled cracking was encountered.

Sawing Control Joints

There was a tendency for other States to follow the lead of Kansas and to form control joints in the plastic concrete rather than saw them. However, some believed that if sawed joints were superior to formed joints, it would be beneficial to have all joints sawed provided the sawing of control joints was feasible. Minnesota's experience showed that it was feasible to saw control joints, and that the best procedure to assure an adequate margin of safety between the time of sawing and the time of cracking was to saw the concrete at an age early enough to produce a slight amount of spalling and water erosion of the joint edges. Under certain favorable conditions such as (1) uniform temperature, (2) aggregates having a low coefficient of thermal expansion, and (3) curing methods having high insulating properties, the sawing of control joints may be deferred until the concrete has hardened sufficiently to prevent spalling and water erosion.

Experience in Virginia, Minnesota, Wisconsin, California, and Colorado on projects utilizing sawed-control joints indicates that concrete placed in the first part of the day or up until 12 or 1 o'clock has a tendency to crack much sooner than that placed in the afternoon. The morning concrete usually cracks the first night after placing, while the afternoon concrete generally cracks the second night. Consequently, it appears advisable to saw the control joints for morning concrete the same afternoon or night unless weather conditions retard the setting of the concrete to such a degree as to make sawing unfavorable.

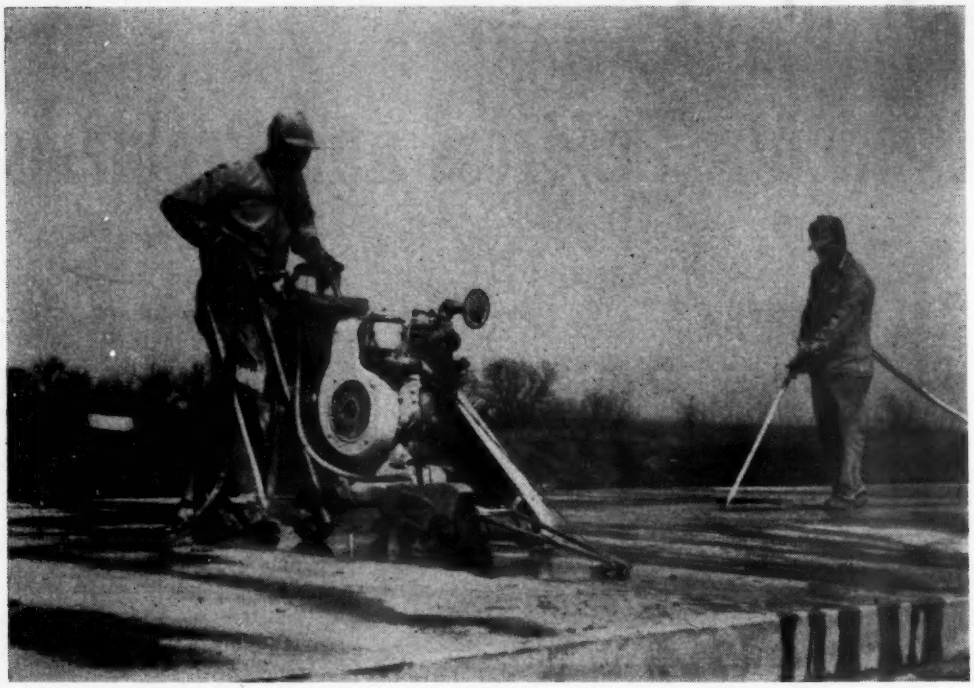
The time required for the concrete to become hard enough to saw without excessive tearing has varied from 4 hours to over 24 hours. The most common way of determining when the concrete has hardened sufficiently to saw without excessive tearing is to make a very short cut with the saw and observe the condition of the joint edges. Other means are being sought to determine the earliest time when the concrete is hard enough to saw. Experience has shown that it is impractical to define the time for sawing as a specific number of hours elapsed after placing the concrete, due primarily to the influence of weather. Hot dry weather accelerates and cool damp weather retards the hardening of the concrete.

Some uncontrolled cracking has been experienced in a number of States where control joints were sawed rather than formed, but in practically all cases when the cracks had a tendency to occur prior to sawing the control joints the trouble was corrected by sawing at an earlier age. There was one exception to this general observation: control joints were being sawed in the early morning within the 24-hour specification limit for concrete placed the previous day and the slab was cracking through while the saw was only part way across the pavement, producing a random crack from the blade to the opposite edge of the slab.

This trouble was remedied by delaying the sawing for several hours. During this time the sun raised the slab temperature and reduced the tensile stresses to the point where sawing could be accomplished without danger of premature rupture. It is probable that earlier sawing in this instance, before shrinkage and contraction stresses approached the rupture point, would also have solved the difficulty. In similar situations where cracking is occurring during the sawing operation and temperatures are not expected to rise, it might be expedient to reduce the depth of saw cut.

Regarding the preceding discussion of control joints, it should be pointed out that the sawing was done with diamond blades which wear out much faster in cutting the green concrete than when cutting the intermediate joints in the older concrete. Consequently this system of sawing control joints in the green concrete and sawing the intermediate joints in the older concrete was preferable to consecutive sawing of all the transverse joints in the green concrete, not only because of the better quality of the joint edges but also for economic reasons. It is reported that, due to the sand particles working loose from the green concrete, blade life in sawing control joints is reduced to approximately one-half that in sawing intermediate joints.

[1] This article was presented at the 35th Annual Meeting of the Highway Research Board, Wash., D. C., Jan. 1956.



Sawing operations of transverse joints and flushing of saw kerf from longitudinal joints.

Consecutive Joint Sawing

In the past 2 years increased use has been made of reinforced silicon carbide discs, in lieu of diamond blades, for sawing concrete made with the relatively softer aggregates such as limestone and slag. It is reported that these abrasive discs permit earlier sawing of the green concrete than diamond blades, and unlike diamond blades have a longer life in sawing green concrete than for sawing older pavement. Consequently the practice with silicon carbide discs has generally been to saw all joints early and consecutively.

Cost of Sawing

From an economical standpoint there appears to be a zone of aggregate hardness where the cost of sawing is approximately equal for diamond and silicon carbide discs. For relatively softer aggregates the silicon carbide is more economical and for harder aggregates the diamond is better. In some instances, silicon carbide discs were used for sawing the control joints and diamond blades were used to saw the intermediate joints.

The cost of sawing joints varies over a wide range depending upon a number of variables such as the type of aggregate, age or hardness of concrete mortar at the time of sawing, depth of cut, type of equipment, and skill of operators. Reported prices per linear foot range from a low of $0.03 to a high of $0.83, and average about $0.35 per linear foot. The largest single item of expense connected with sawed joints is the blade cost, which for a 12- by ⅛-inch diamond blade averages about $150. Reports on various experimental projects indicate that the blade life ranges from about 400 to 6,000 linear feet and averages approximately 1,500 linear feet. The cost of silicon carbide discs ranges from $5 to $18 per disc which is 10 percent or less of the cost of diamond blades.

Some attempt has been made to correlate blade life with aggregate hardness as measured by the percentage loss in the Los Angeles Rattler test, however the relation is inconsistent in some instances. Two States have reported that the presence of a small percentage of flint in the coarse aggregate caused silicon carbide discs to break. Apparently when a disc strikes a piece of the hard flint rock, it is deflected from a straight cut and an excessive bending movement causes the disc to shatter.

A comparison between the cost of forming and the cost of sawing joints is difficult due to the wide range in sawing costs. On several projects where aggregates were relatively hard, the cost of sawing was reported as approximately double that for forming joints. On numerous other projects, costs for sawing and forming were estimated to be equal. Certain benefits resulting from the sawing practice are difficult to evaluate, such as elimination of mixer shutdowns to allow the joint forming operations to catch up, and reduction of time between placing the concrete and applying the curing compound.

Sawing Longitudinal Joint

Some States have experimented with the sawing of the longitudinal joint as well as transverse joints. From their experience it has been found that the time interval before sawing is not critical, and the cost of sawing longitudinal joints is comparable with that for sawing intermediate transverse contraction joints.

Single-Lane Construction

Most of the pavements where sawed joints have been tried were placed full width or two lanes constructed at the same time, and the preceding observations apply to that type of construction only. Where a single lane is placed and the adjacent lane is constructed later, a serious construction problem is presented in placing and forming joints in the second lane. If the temperature drops after the second lane has been placed, the hardened concrete in the first lane contracts and joints in it that have cracked through open up. This movement is transferred to the green concrete slab by way of the tie bars and edge friction, thereby adding external stresses to the internal stresses caused by hardening, shrinkage, and temperature contraction.

California experimented with this type of construction and found that, at times, the initial lane transmitted enough stress to the second lane to result in an uncontrolled crack before the concrete had set hard enough in the latter to permit sawing. Subsequently other States had similar experiences, and some solved the problem by using formed joints in the second lane opposite every open joint in the first lane. Others, due to favorable local conditions such as relatively soft aggregates and moderate temperature fluctuations, have successfully eliminated uncontrolled cracking in

Sealing operation with cold-poured joint material.

this type of construction by very early sawing. The use of insulation applied to the surface of both lanes has not yet been reported by any State, but from theoretical considerations it would seem to be worth trying.

Design Problems

Joint depth

The sawed-joint technique has not necessarily created a new problem concerning the depth of cut, since the depth of a formed joint adequate to control the location of cracking will also be adequate depth for a sawed joint. There is one important difference. The cost of forming joints does not vary appreciably with the depth. Consequently, it has been customary to allow a generous safety factor in specifications for depth of formed joints. On the other hand, the cost of sawing varies pronouncedly with the depth. It is reported that a 2-inch cut costs over twice as much as a 1-inch cut.

Several States have varied the depth of cut from 1 to 2 inches on 8- and 9-inch slabs. Due to varying local conditions the 1-inch cut was found to be adequate in some States and inadequate in others. In all instances it was reported that 1½-inch depth of cut was satisfactory for both transverse and longitudinal joints.

Colorado reports that with 1-inch cuts in 8-inch slabs all the joints cracked through, but cracks of various lengths developed about 1 to 2 inches alongside of and roughly parallel to the saw cut. These cracks were from a few inches to several feet in length and would start and end at the saw cut. It is their belief that these cracks formed around the larger aggregate particles lying close to the surface. The maximum size of aggregate was 2 inches in this case. It is believed that aggregate size is a factor in determining the minimum depth of cut.

Joint spacing

The question as to the optimum spacing of joints has been present since the earliest days of concrete paving, and the advent of sawed joints has little effect upon the problem except as related to joint width and sealing.

Width of cut and sealing

While sawed joints may be cut the same width as formed joints, they generally are narrower—being about ⅛ inch when diamond blades are used and ¼ inch with silicon carbide discs. Wider joints may be obtained by making a second cut parallel to the first and usually shallower. The intervening concrete may be broken out with hand tools. Obviously this would materially increase the cost of jointing.

Until special equipment was made available, it was difficult to introduce seal material into the narrow ⅛-inch diamond blade cuts. After elimination of this difficulty, there still remained the question as to whether or not a ⅛-inch cut provided a reservoir for sufficient seal material to withstand the stretch to which it is subjected when the joints open in cold weather. On one project having 50-foot slabs, joints which were originally cut ⅛ inch measured ⅜ inch at near freezing temperature. This indicates a stretch of 200 percent for the seal material which is considerably above the 50 percent stretch commonly specified for seals.

Opinions vary regarding the importance of obtaining a perfect seal against moisture and foreign matter, possibly due to varying local conditions. Several States are experimenting with unsealed sawed joints; however available data are insufficient to warrant the drawing of conclusions. The gathering of data regarding joint openings has been greatly simplified with the advent of sawed joints. The smooth vertical faces of the saw cut make it relatively easy to measure joint widths by means of calipers or thickness gages, thus eliminating the necessity for casting reference plugs in the concrete as was formerly required.

Curing of Concrete

The curing method used is probably of greater importance for sawed-joint construction than for formed-joint construction. The effectiveness of the curing method with regard to water retention and insulating value affects the shrinkage stresses in the pavement, and is related to the time of sawing and joint spacing. Various types of cures have been used in conjunction with sawed joints, and apparently successful application of sawed-joint construction is not dependent upon the use of any one type of cure as was formerly believed by some highway engineers.

Sawing Equipment

A variety of sawing equipment is available from a number of manufacturers. There are manually pushed saws with single blades and self-propelled saws having one or several blades in tandem. The relative merits of the different types have not yet been evaluated. A separate water tank is usually required to provide ample water for cooling the blade and washing the saw kerf from the joint.

The WASHO Road Test—A Motion Picture

The Bureau of Public Roads has produced and released a motion picture, *The WASHO Road Test*, depicting the operation and major findings of the large-scale road test undertaken cooperatively by the Western Association of State Highway Officials, the Bureau of Public Roads, and the motor-vehicle and petroleum industries, and conducted under the direction of the Highway Research Board. The object of the test was to determine the effect of heavy traffic on bituminous pavements, specially built for the purpose near Malad, Idaho.

In essence, the test was planned to compare the performance of different designs of bituminous pavements, all laid on a uniform soil subgrade, under controlled truck traffic of varying axle arrangement and load. Traffic operations ran from November 1952 through May 1954. Analysis of the countless data obtained with a wide variety of tests and instruments, some newly created for the job, continued for more than a year thereafter. The design, construction, and testing procedures of the WASHO Road Test are fully detailed in HRB Special Report 18, and the test data, analyses, and findings in HRB Special Report 22, both published by the Highway Research Board, 2101 Constitution Ave., N. W., Washington 25, D. C.

The WASHO Road Test motion picture (16-millimeter, color and sound; running time 35 minutes) was produced by the Bureau of Public Roads as a visual summary of the published reports with the authorization and endorsement of the WASHO Advisory Committee of the Highway Research Board.

The WASHO Road Test film may be borrowed by any responsible organization upon application to the nearest office listed below. There is no charge for such loans except for the shipping costs. Loans can be made only for short periods of time. Several alternate dates should be proposed, and the request should be made well in advance of a planned showing.

WASHINGTON, D. C.: Research Reports Branch, Bureau of Public Roads, Washington 25, D. C.

SAN FRANCISCO, CALIF.: Division Engineer, Bureau of Public Roads, Room 102 Old Mint Bldg., 5th & Mission Sts., San Francisco 3, Calif.

PORTLAND, OREG.: Division Engineer, Bureau of Public Roads, 753 Morgan Bldg., 720 S. W. Washington St., Portland 8, Oreg.

Those who wish to purchase prints of the motion picture *The WASHO Road Test* should write to R. E. Royall, Chief, Research Reports Branch, Bureau of Public Roads, Washington 25, D. C., for authority to do so and for information on the purchase procedure. Prints will cost $141 each, but do not send your money to Public Roads. The request for authority to purchase prints must include the following statement:

"Assurance is hereby given that the composition of the motion picture will not be altered in any way, either by addition or deletion, and that it will be shown only in its entirety."

U. S. GOVERNMENT PRINTING OFFICE: 1956

A list of the more important articles in PUBLIC ROADS may be obtained upon request addressed to Bureau of Public Roads, Washington 25, D. C.

PUBLICATIONS of the Bureau of Public Roads

The following publications are sold by the Superintendent of Documents, Government Printing Office, Washington 25, D. C. Orders should be sent direct to the Superintendent of Documents. Prepayment is required.

ANNUAL REPORTS

Work of the Public Roads Administration:
1941, 15 cents. 1948, 20 cents.
1942, 10 cents. 1949, 25 cents.
Public Roads Administration Annual Reports:
1943; 1944; 1945; 1946; 1947.
(*Free from Bureau of Public Roads*)
Annual Reports of the Bureau of Public Roads:
1950, 25 cents. 1952, 25 cents. 1954 (out of print).
1951, 35 cents. 1953, 25 cents. 1955, 25 cents.

PUBLICATIONS

Bibliography of Highway Planning Reports (1950). 30 cents.
Braking Performance of Motor Vehicles (1954). 55 cents.
Construction of Private Driveways, No. 272MP (1937). 15 cents.
Criteria for Prestressed Concrete Bridges (1954). 15 cents.
Design Capacity Charts for Signalized Street and Highway Intersections (reprint from PUBLIC ROADS, Feb. 1951). 25 cents.
Electrical Equipment on Movable Bridges, No. 265T (1931). 40 cents.
Factual Discussion of Motortruck Operation, Regulation, and Taxation (1951). 30 cents.
Federal Legislation and Regulations Relating to Highway Construction (1948). Out of print.
Financing of Highways by Counties and Local Rural Governments: 1931–41, 45 cents; 1942–51, 75 cents.
General Location of the National System of Interstate Highways, Including All Additional Routes at Urban Areas Designated in September 1955. 55 cents.
Highway Bond Calculations (1936). 10 cents.
Highway Bridge Location No. 1486D (1927). 15 cents.
Highway Capacity Manual (1950). $1.00.
Highway Needs of the National Defense, House Document No. 249 (1949). 50 cents.
Highway Practice in the United States of America (1949). 75 cents.
Highway Statistics (annual):
1945 (out of print). 1949, 55 cents. 1953, $1.00.
1946, 50 cents. 1950 (out of print). 1954, 75 cents.
1947, 45 cents. 1951, 60 cents.
1948, 65 cents. 1952, 75 cents.
Highway Statistics, Summary to 1945. 40 cents.
Highways in the United States, *nontechnical* (1954). 20 cents.
Highways of History (1939). 25 cents.
Identification of Rock Types (reprint from PUBLIC ROADS, June 1950). 15 cents.
Interregional Highways, House Document No. 379 (1944). 75 cents.
Legal Aspects of Controlling Highway Access (1945). 15 cents.
Local Rural Road Problem (1950). 20 cents.
Manual on Uniform Traffic Control Devices for Streets and Highways (1948) (*including 1954 revisions supplement*). $1.00.
Revisions to the Manual on Uniform Traffic Control Devices for Streets and Highways (1954). *Separate*, 15 cents.

PUBLICATIONS (Continued)

Mathematical Theory of Vibration in Suspension Bridges (1950). $1.25.
Model Traffic Ordinance (revised 1953). Out of print.
Needs of the Highway Systems, 1955–84, House Document No. 120 (1955). 15 cents.
Opportunities in the Bureau of Public Roads for Young Engineers (1955). 25 cents.
Principles of Highway Construction as Applied to Airports, Flight Strips, and Other Landing Areas for Aircraft (1943). $2.00.
Progress and Feasibility of Toll Roads and Their Relation to the Federal-Aid Program, House Document No. 139 (1955). 15 cents.
Public Control of Highway Access and Roadside Development (1947). 35 cents.
Public Land Acquisition for Highway Purposes (1943). 10 cents.
Public Utility Relocation Incident to Highway Improvement, House Document No. 127 (1955). 25 cents.
Results of Physical Tests of Road-Building Aggregate (1953). $1.00.
Roadside Improvement, No. 191MP (1934). 10 cents.
Selected Bibliography on Highway Finance (1951). 60 cents.
Specifications for Construction of Roads and Bridges in National Forests and National Parks, FP-41 (1948). $1.50.
Standard Plans for Highway Bridge Superstructures (1953). $1.25.
Taxation of Motor Vehicles in 1932. 35 cents.
Tire Wear and Tire Failures on Various Road Surfaces (1943). 10 cents.
Transition Curves for Highways (1940). $1.75.

MAPS

State Transportation Map series (available for 39 States). Uniform sheets 26 by 36 inches, scale 1 inch equals 4 miles. Shows in colors Federal-aid and State highways with surface types, principal connecting roads, railroads, airports, waterways, National and State forests, parks, and other reservations. Prices and number of sheets for each State vary—see Superintendent of Documents price list 53.
United States System of Numbered Highways. 28 by 42 inches, scale 1 inch equals 78 miles. 20 cents.

Single copies of the following publications are available to highway engineers and administrators for official use, and may be obtained by those so qualified upon request addressed to the Bureau of Public Roads. They are not sold by the Superintendent of Documents.

Bibliography on Automobile Parking in the United States (1946).
Bibliography on Highway Lighting (1937).
Bibliography on Highway Safety (1938).
Bibliography on Land Acquisition for Public Roads (1947).
Bibliography on Roadside Control (1949).
Express Highways in the United States: a Bibliography (1945).
Indexes to PUBLIC ROADS, volumes 17–19 and 23.
Title Sheets for PUBLIC ROADS, volumes 24–28.

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DEPARTMENT OF COMMERCE - BUREAU OF PUBLIC ROADS

STATUS OF FEDERAL-AID HIGHWAY PROGRAM

AS OF FEBRUARY 29, 1956

(Thousand Dollars)

STATE	UNPROGRAMMED BALANCES	ACTIVE PROGRAM											
		PROGRAMMED ONLY			PLANS APPROVED, CONSTRUCTION NOT STARTED			CONSTRUCTION UNDER WAY			TOTAL		
		Total Cost	Federal Funds	Miles	Total Cost	Federal Funds	Miles	Total Cost	Federal Funds	Miles	Total Cost	Federal Funds	Miles
Alabama	$7,949	$19,544	$10,688	230.9	$7,554	$4,155	42.9	$37,611	$19,830	599.6	$64,709	$34,673	873.4
Arizona	2,625	7,378	5,583	133.4	4,478	3,044	43.0	9,271	6,814	111.3	21,127	15,441	287.7
Arkansas	11,780	14,261	7,483	507.6	3,137	1,551	26.4	20,855	10,731	412.1	38,253	19,765	946.1
California	7,054	28,597	15,223	177.2	14,712	8,194	16.1	151,995	77,879	318.4	195,304	101,296	511.7
Colorado	16,452	6,750	3,737	98.4	3,938	2,310	43.2	14,772	7,787	158.4	25,460	13,834	300.0
Connecticut	22,472	1,440	825	5.5	702	347	1.1	11,637	5,791	14.9	13,779	6,963	21.5
Delaware	5,101	1,909	974	6.2	2,563	1,303	42.1	4,859	2,434	28.0	9,331	4,711	76.3
Florida	8,146	15,541	8,365	194.3	12,848	6,706	60.2	33,901	17,359	343.7	62,290	32,430	598.2
Georgia	21,633	26,351	13,598	418.2	5,241	2,481	43.2	43,284	20,366	713.0	74,876	36,445	1,174.4
Idaho	6,794	6,685	4,329	92.0	1,389	966	32.1	12,427	8,124	149.2	20,501	13,419	273.3
Illinois	15,963	36,460	19,742	522.8	33,140	18,033	99.6	81,182	43,922	375.0	150,782	81,697	997.4
Indiana	27,043	22,407	11,435	235.0	15,763	7,909	104.7	38,117	21,294	89.0	76,287	40,638	428.7
Iowa	8,785	22,839	13,152	783.6	13,366	6,815	198.3	17,668	9,547	713.7	53,873	29,514	1,695.6
Kansas	10,967	14,672	7,654	864.2	5,557	2,921	103.8	21,349	11,002	768.6	41,578	21,577	1,736.6
Kentucky	15,452	4,429	2,430	42.2	2,554	1,694	2.7	38,690	20,172	585.3	45,673	24,296	630.2
Louisiana	9,799	15,187	7,608	94.2	6,231	3,115	4.5	44,583	21,192	485.8	66,001	31,915	584.5
Maine	7,781	2,974	1,555	26.6	86	86		15,228	7,859	107.9	18,288	9,500	134.5
Maryland	5,757	25,777	13,232	73.2	11,314	5,493	14.4	16,451	8,706	61.2	53,542	27,431	148.8
Massachusetts	13,570	12,143	6,062	18.5	19,353	10,220	20.6	36,470	17,567	50.5	67,966	33,849	89.6
Michigan	12,299	40,258	20,340	653.4	21,692	12,198	102.6	53,198	27,001	369.0	115,148	59,539	1,125.0
Minnesota	11,026	17,328	8,735	929.6	10,504	6,022	197.5	27,075	14,452	507.8	54,907	29,209	1,634.9
Mississippi	12,260	11,845	6,001	446.4	3,770	1,983	142.6	25,974	13,334	620.8	41,589	21,318	1,209.8
Missouri	7,795	27,281	13,957	1,179.3	7,314	3,895	29.3	75,788	39,695	1,154.8	110,383	57,547	2,363.4
Montana	17,392	9,391	5,804	172.9	4,212	2,446	80.2	22,821	14,299	386.7	36,424	22,549	639.8
Nebraska	13,549	18,557	9,682	784.0	8,072	4,179	163.4	23,783	12,764	709.1	50,412	26,625	1,656.5
Nevada	11,439	2,330	1,992	22.5	2,349	1,940	38.7	6,578	5,567	146.8	11,257	9,499	208.0
New Hampshire	6,277	2,633	1,406	14.0	595	300	2.4	8,395	4,322	52.7	11,623	6,028	69.1
New Jersey	20,981	16,165	7,898	74.2	5,376	2,344	8.7	30,491	14,266	36.3	52,032	24,508	119.2
New Mexico	7,190	4,120	2,596	43.2	3,995	2,601	75.3	10,935	7,222	178.2	19,050	12,419	296.7
New York	52,667	32,138	16,642	112.6	49,688	25,441	85.9	200,936	93,100	242.5	282,762	135,183	441.0
North Carolina	13,738	20,389	10,163	417.3	6,460	3,141	62.1	47,035	23,227	586.6	73,884	36,531	1,066.0
North Dakota	5,554	15,092	7,685	1,419.7	6,585	3,425	481.5	8,873	4,535	491.7	30,550	15,645	2,392.9
Ohio	25,770	46,890	24,092	175.6	17,491	9,256	29.8	67,273	32,545	102.6	131,654	65,893	308.0
Oklahoma	14,873	16,359	8,219	393.3	11,443	5,978	101.0	36,007	18,901	359.1	63,809	33,098	853.4
Oregon	4,597	4,231	2,533	60.8	3,298	2,017	32.5	23,822	14,695	221.6	31,351	19,245	314.9
Pennsylvania	30,229	21,650	11,178	73.3	59,505	29,179	64.5	84,345	42,746	311.3	165,500	83,103	449.1
Rhode Island	1,647	4,010	2,010	13.2	1,386	693	1.0	19,575	10,100	28.9	24,971	12,803	43.1
South Carolina	11,384	16,333	8,856	352.8	2,496	1,321	31.2	18,087	9,455	329.7	36,916	19,632	713.7
South Dakota	1,296	23,869	13,712	925.6	6,393	3,775	199.5	12,782	7,373	562.2	43,044	24,860	1,687.3
Tennessee	17,740	18,029	9,021	523.1	10,476	5,241	70.4	40,135	18,265	329.6	68,640	32,527	923.1
Texas	19,793	27,176	13,806	637.1	24,957	13,322	201.4	110,234	58,082	1,622.0	162,367	85,210	2,460.5
Utah	5,030	4,978	3,723	160.1	1,279	977	19.7	12,032	9,017	126.7	18,289	13,717	306.5
Vermont	4,503	2,927	1,464	14.4	914	444	2.4	8,244	4,314	87.0	12,085	6,222	103.8
Virginia	16,186	17,175	8,825	261.7	5,516	2,912	26.6	26,221	12,888	306.7	48,912	24,625	595.0
Washington	6,777	23,418	13,128	354.0	3,176	1,764	71.1	21,990	11,696	172.2	48,584	26,588	597.3
West Virginia	16,368	10,023	5,271	43.0	2,602	1,319	4.3	17,470	8,770	65.1	30,095	15,360	112.4
Wisconsin	13,725	17,689	8,905	251.7	8,720	4,744	80.6	44,435	22,004	415.8	70,844	35,653	748.1
Wyoming	337	10,602	6,984	213.9	1,960	1,294	48.6	13,568	8,896	232.2	26,130	17,174	494.7
Hawaii	4,517	2,799	1,390	8.0	3,177	1,571	2.9	5,575	2,547	12.8	11,551	5,508	23.7
District of Columbia	9,574	4,492	2,246	3.4	384	191	.5	9,728	4,392	3.3	14,604	6,829	7.2
Puerto Rico	11,637	4,672	2,277	24.8				15,789	7,213	53.1	20,461	9,490	77.9
TOTAL	633,273	780,193	414,216	15,282.9	459,711	243,256	3,357.1	1,779,544	916,059	16,910.5	3,019,448	1,573,531	35,550.5